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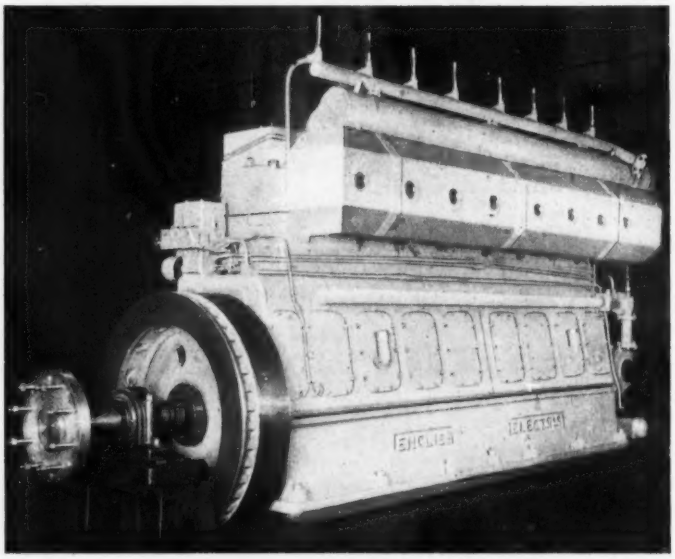
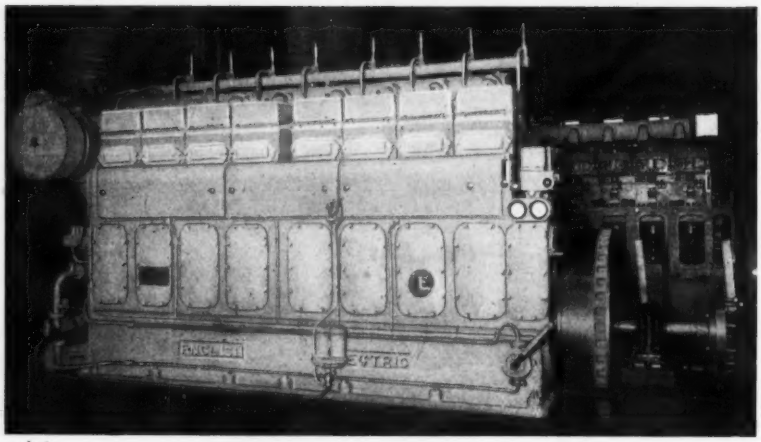
"English Electric" Pressure-charged Diesel Engines.





Two views of an "English Electric" 8SK Pressure-charged Oil Engine, 660 H.P. at 600 R.P.M.

The English Electric Journal

Vol. X. No. 10 DECEMBER, 1944. One Shilling

Some Interim Notes on the Turbo Pressure-Charging of Four-Stroke Diesel Engines.

By G. H. PAULIN, M.I.Mech.E., M.I.Mar.E., Chief Engineer, Internal Combustion Department.

The application of exhaust gas turbo-charging to Diesel engines, whilst not a new thing, has come into more general acceptance comparatively recently. It is considered that the turbo-charging of four-stroke engines will extend greatly and that the majority of these engines in future will be so arranged. This article has been written for the information and interest of those of our readers who may not be familiar with the subject or who may become associated with engines fitted with the system of turbo-pressure charging which is described.

Since the building of prime movers began, designers have made continuous efforts to improve efficiencies—to get more and more from a given size of machine or weight of material. Great progress has been made in this direction. Some noteworthy advances have been achieved, but in no field has the progress been greater than in that of the internal combustion engine. Over a considerable number of years, in the case of the true Diesel engine—that is, the engine in which the fuel is injected by means of high pressure air—the progress was relatively slow. Rotational speeds rose gradually; brake mean effective pressures (B.M.E.P.) in a few cases were increased a little; weights were reduced to a small extent. Even so, the piston speeds remained at or around the 800 ft./min. figure; the weights about 300 lb./B.H.P. and higher.

The real advance began with the production of reliable, accurately functioning fuel injection equipment. From that time speeds began to rise, the air injection of fuel fell into disuse, the size and weight of engines began to fall rapidly.

It became evident quite soon, however, that the limiting factor in engine performance (B.M.E.P.) could not be raised above a fairly well defined figure without encountering excessive temperatures. The problem became one of air supply. Clearly, the amount of air an engine can inspire naturally, is limited. The size of the air inlet valve is governed by the cylinder diameter, and the velocity of the indrawn air through the valve and associated passages, by the piston speed. An air velocity is soon reached where the "breathing" of the engine is prejudiced seriously.

Consideration was then given to means for charging the cylinders with more air. In the earlier stages of the work it was thought that the simple raising of the pressure of the charge of combustion air would be sufficient. Up to a point this is so, but as this increase of pressure is accompanied by an increase of temperature, limits were soon imposed in this direction. Various methods of pressure-charging have been and are, used. These may be classed in two main groups :—

(1) Low-pressure air pumps driven by the engine itself or independently by electric motor or small blowing engine.

These pumps may be of the positive displacement type (Roots and similar) or of the centrifugal design.

(2) Exhaust gas driven turbo-blowers.

In addition to (1) and (2) there is the tuned intake pipe system which provides for an intake pipe of the proper length to induce a natural oscillation frequency of the air column in the pipe coincident with that of the inlet valve opening. The kinetic energy of the oscillating air column provides a ramming effect on the cylinder air charge. This system has been further developed by the Polish engineers Wicenski and Bujak, in conjunction with the use of special inlet cams; the inventors claim from 25 to 40

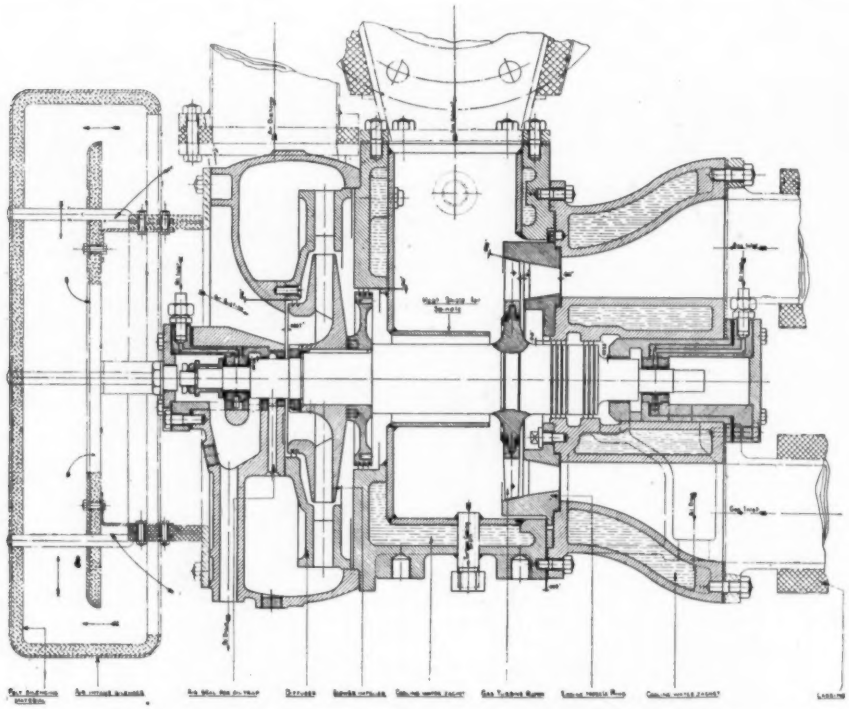


Fig. 1.—Sectional arrangement of Supercharger for Type 6SH Diesel Engine.

per cent. increase in engine output, but the system is clearly of use for constant speed only.

Certain claims are made for all the methods described. If an increased amount of air is delivered into the engine cylinders, some results, in the form of increased power, are to be expected. There may, however, be disadvantages either from an operating or from an economic aspect. For example, virtually all direct-driven pressure-charging equipment has the undesirable characteristics :—

(*a*) The volume of air cannot be controlled to conform to load variation.

(*b*) A system of pressure-charging which produces only 20 to 25 per cent. net increase in engine output cannot be regarded as economically sound.

The arrangement which has come most into use is that known as the Buchi System of exhaust gas pressure-charging. This system has had very wide acceptance. It is claimed that the total of Buchi turbo-charged engines is now considerably in excess of 4,000,000 H.P. with individual engine ratings up to 6,000 H.P.

It is interesting to know that Dr. Buchi, the inventor of the system, filed, as early as 1905, a patent advancing the utilisation, in gas turbines, of the exhaust gases from internal combustion engines. This patent outlined the pre-compression of the charging air of internal combustion engines by means of turbo-blowers, and suggested cooling of the charging air during and after the compression, as well as the use of exhaust gases in the turbine, without water injection.

The first tests of exhaust gas turbine-driven pressure-chargers were conducted by Dr. Buchi in 1911, in Switzerland. The original tests employed a constant pressure to serve the turbine and, as might be expected with such an advanced (at that time) idea, a long period elapsed before the development had reached practicability and anything approaching general acceptance. The most important single factor in the evolution of the system was the discarding of the constant pressure feature for the present method of creating timed pressure pulsations in the exhaust pipes. This provided a means of efficient scavenging of the engine cylinders with low pressure of air, and made possible increases in output with lower charging pressures than would be possible otherwise.

During the last war (1914-18) Professor Rateau also used exhaust gas turbines on aeroplane engines in France, but his system did not include the wide valve overlap period and scavenge process which is the highly important factor in

the Buchi System. In the earlier Rateau applications serious troubles were experienced with blading and other features of the gas turbine, and the scheme was dropped in favour of a simpler arrangement of centrifugal blower driven from the engine crankshaft and geared up to relatively high speeds—much on the lines used now on many aeroplane engines.

The Buchi System comprises an exhaust gas driven turbine and compressor, mounted on or near the engine, and arranged to deliver the compressed air into the induction system of the engine. Fig. 1 shows a sectional arrangement of a turbo-blower designed and manufactured by The English Electric Company for use on a six-cylinder 1,500 r.p.m. engine, also made by the Company. The combined turbo-compressor consists of a single-stage impulse turbine with blading designed on the vortex principle, i.e., having a greater pressure drop across the tip section of the blade than the root section—with a centrifugal blower mounted on the same shaft. The turbine is driven by the exhaust gases from the engine. The turbine and blower are mounted in the same housing, with a system of labyrinth glands to prevent gas and air leakage from their respective compartments. The rotor of this blower operates at speeds up to a maximum of 26,000 r.p.m. and the shaft runs in plain bearings, whitemetal lined, forced lubricated by a small pump mounted on the engine. An independent self-contained lubricating oil system is used, with sight glasses indicating the rate of flow through the system. The water cooling system of the pressure charger is coupled up with that of the engine.

Turbo-chargers for larger engines follow the same general design, but have their own self-contained lubricating oil pumps. The rotor speeds in the larger sizes are much lower than in the case of the small machines represented by Fig. 1.

The exhaust gases from the engine cylinders are delivered to the turbine at a mean pressure of about 2 to 3 lb./sq. in. above atmospheric pressure. The air from the blower is delivered to the engine inlet manifold at a pressure of about $3\frac{1}{2}$ to $5\frac{1}{2}$ lb./sq. in. above atmospheric pressure.

In order considerably to increase the output of an engine, it is not only necessary to increase the pressure of the charging air, but it is also a matter of prime importance to scavenge adequately the working cylinders and combustion spaces with clean and relatively cool air. This scavenging is regarded as essential, and to achieve it the exhaust and air inlet cams have extra long opening periods, with their phasing such that an overlap (or simultaneous opening of both valves) of up to 140° and sometimes more, is provided. Fig. 2 shows a typical valve period diagram.

While both valves are open the comparatively cool charging air flows over the surface of the inlet valve, piston crown and exhaust valve, removing in the process the inert gases from the combustion spaces and cooling effectively the valves and piston crown. The temperature of the exhaust gases is also reduced by admixture of the charging air. As the piston moves away from dead centre, on the suction stroke, the cylinder is charged thoroughly with fresh cool air at a pressure above atmospheric.

The maximum output of an internal combustion engine, with a given swept volume, is determined by the complete burning of a definite quantity of fuel in relation to the weight of air contained in the cylinder. With the lighter types of fuels, about 14.2 lbs. of air are required (theoretically) to burn 1 lb. of fuel. In reality nothing like this quantity of fuel can be burned completely with this weight of air as it is impossible, particularly in oil engines, to achieve so perfect a distribution of fuel throughout the air in the combustion space that every part of air is mixed properly with its correct share of fuel. The proportion of air required to fuel has been of the order of 40 : 1, but with the advances in the design and production of fuel injection equipment and the increasing knowledge of the effect of combustion space design this ratio is now probably nearer 25 : 1.

The weight of the air charge introduced into the cylinder is directly proportional to the absolute pressure of the charging, or boost, air and is also inversely proportional to its absolute temperature. The adiabatic terminal temperature in the compressor rises with increasing pressure, so that the limitation on boost pressure will be apparent, namely, that the rate of increase of air charge weight and the consequent rate of

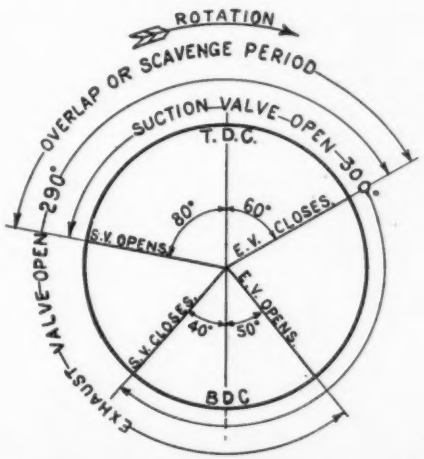


Fig. 2.—Valve timing diagram for high-speed compression-ignition pressure-charged engine.

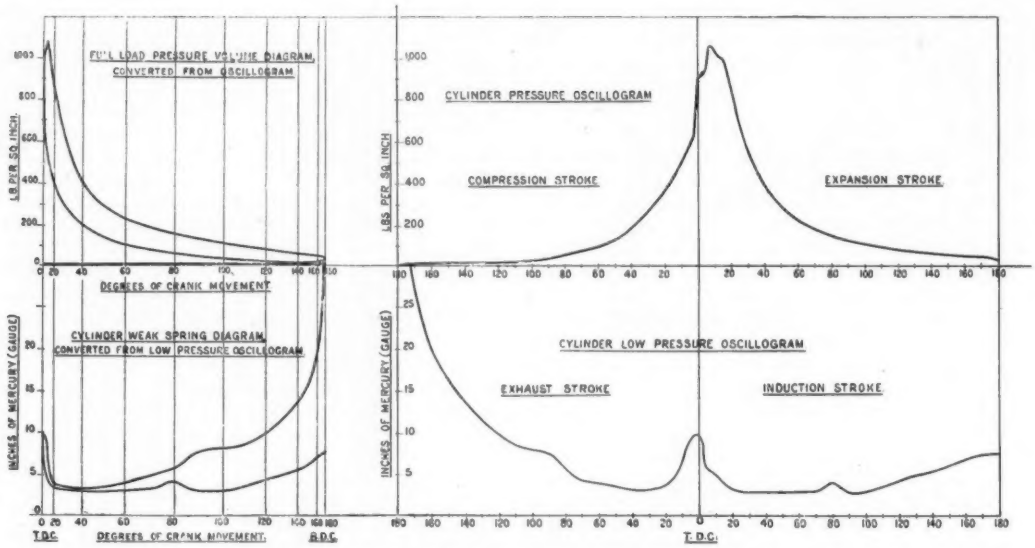


Fig. 3.—Cylinder pressure oscillograms.

increase in engine output fall off as the boost pressure rises. At the same time, the compressor efficiency falls and the power required to drive it increases, which means increased back pressure on the exhaust system, with attendant difficulties.

It is for these reasons that normal commercial engines, at present, are operated with the relatively low charging air pressures mentioned earlier. With pressures appreciably higher, direct cooling of the charging air becomes necessary, but since cooling of the charging air gives a smaller specific volume the question of increase of compressor output must then be considered.

It might be desirable here to refer in a little more detail to the matter of back pressure. The question has been asked : " Is not the back pressure set up by the turbine very prejudicial to the engine ? " In the case of the system in discussion, exhaust gas energy, which would go to waste in a normal engine, is utilised in driving the turbine. With a good turbo-blower the mean pressure required to drive it is about 3 lb./sq. in. In a naturally aspirated engine, or one where the blower is driven direct by the engine, the back pressure is of the order of about 1 lb./sq. in. or a little higher. It will be seen therefore that the debit against the engine, on account of blower operation, is very small.

It has been stated earlier that an essential feature of the Buchi System of pressure-charging is the scavenging process. One of the factors necessary for this scavenging is the valve overlap. The other is the use, in engines with four cylinders and over, of a special arrangement of multiple exhaust manifolding. This arrangement allows of more or less complete scavenging of one cylinder before the exhaust valve on another cylinder connected to the same manifold opens. Overlap of exhaust periods in the particular manifold is therefore avoided. Simultaneously the pressure waves in the manifold play a very important part in the scavenging process.

It should be appreciated, however, that there is no question of resonant vibration of the column of gases in the manifold. The natural frequency of oscillation is comparatively high, so that the relevant exciting harmonics are too small to create appreciable resonant vibrations. The pressure fluctuations in the Buchi System depend on the filling and discharging of the exhaust pipe and are of precise form, regularity and phase, not affected by alterations in engine speed or fluctuations in load.

The essential feature of the Buchi System is that the exhaust pipe pressure falls to a minimum each time the scavenging process is taking place in a cylinder, this minimum being well below the charging air pressure ; there is therefore no possibility of back flow through the engine valves. The charging air pressure remains constant and is in no way affected by the pressure fluctuations in the exhaust manifolding. The correct position and length of the periods of minimum pressure are of great importance ; the periods must clearly be long enough to cover the scavenging periods. The energy necessary for driving the turbine and compressing the charging air is provided by the intervening periods of high pressure. The appropriate area of discharge

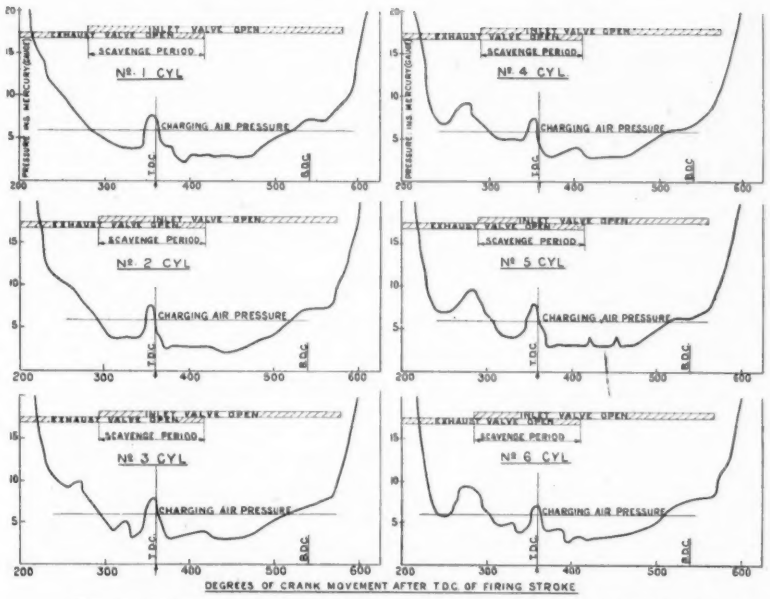


Fig. 4.—Cylinder low-pressure diagrams taken at 220 B.H.P., 1250 R.P.M.

of the turbine nozzle ring and the volume of the exhaust manifolding provide the pressure fluctuation for the required maximum and minimum pressures. The cross section of the exhaust passages and manifold dictate the pressure of the wave front. It will be appreciated that, if the frequency of the pressure fluctuations is such that periods of higher pressure are phased at or near the period of inlet valve opening, the fundamental principle of the whole charging process is destroyed.

Figs. Nos. 3, 4 and 5 show very clearly the pressure conditions in the cylinders and exhaust manifolding. Further reference will be made later to these diagrams. The subdivision of the exhaust manifolding is carried from the exhaust outlets in the cylinder heads to the gas entries on the turbine. The splitting up of the manifolding is arranged according to the number of engine cylinders and firing order, as tabulated below and shown in Fig. 6 :—

4	cylinders	... 2	manifolds.
5	,,	... 3	,,
6	,,	... 2	,,
7	,,	... 3	,,
8	,,	... 4	,,

In the case of the 7-cylinder engine, further experience tends to indicate that better scavenge conditions would accrue from the use of four manifolds.

The purpose of this sub-division is to prevent the scavenging process in any cylinder from being interfered with by a period of high exhaust pressure caused by another cylinder.

The importance of this manifolding and its effect on the functioning of the system are illustrated in Table I. A five-cylinder engine, 15 in. bore, 20 in. stroke, 375 r.p.m., was fitted in the first place with two manifolds and a two-entry turbine, the arrangement of the manifolding being as shown in Fig. 7. The performance data are shown in Column A, Table I, and were regarded as definitely unsatisfactory. Full output was not obtainable within the temperature limits and other conditions permitted.

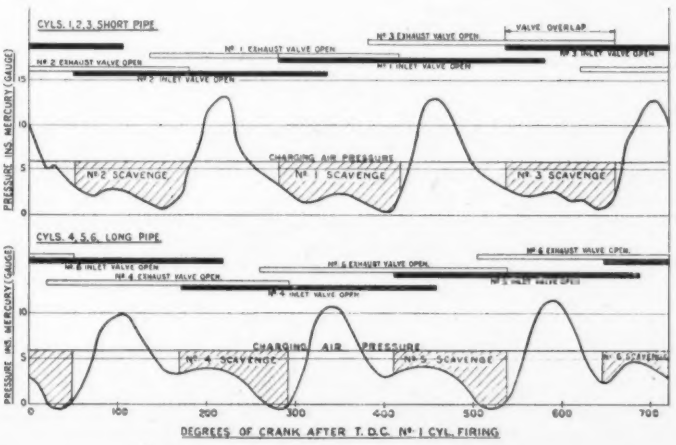

CYLS. 1,2,3. SHORT PIPE
Nº 3 EXHAUST VALVE OPEN
VALVE OVERLAP
Nº 1 EXHAUST VALVE OPEN
Nº 2 EXHAUST VALVE OPEN
Nº 1 INLET VALVE OPEN
Nº 3 INLET VALVE OPEN
Nº 2 INLET VALVE OPEN
CHARGING AIR PRESSURE
Nº 2 SCAVENGE
Nº 1 SCAVENGE
Nº 3 SCAVENGE
CYLS. 4,5,6. LONG PIPE
Nº 6 EXHAUST VALVE OPEN
Nº 5 EXHAUST VALVE OPEN
Nº 4 EXHAUST VALVE OPEN
Nº 6 INLET VALVE OPEN
Nº 5 INLET VALVE OPEN
Nº 4 INLET VALVE OPEN
CHARGING AIR PRESSURE
Nº 4 SCAVENGE
Nº 5 SCAVENGE
Nº 6 SCAVENGE
PRESSURE INS. MERCURY (GAUGE)
DEGREES OF CRANK AFTER T.D.C. Nº 1 CYL. FIRING

Fig. 5.—Exhaust pipe pressure diagrams.

TABLE I.

COMPARISON BETWEEN TWO AND THREE BRANCH CHARGERS.

5SL Engine No. IH. 731.

	A. Two Branch Charger.	B. Three Branch Charger.
Engine.		
Load %	55.5	55.5
B.H.P.	485	485
B.M.E.P. lb./sq. in. ...	58.3	58.3
Max. cylinder pressure lb./sq. in.	666	690
Exhaust temp. (cylinder branches) °F.	654	603
Fuel consumption lb./B.H.P./hr.	0.407	0.376
Turbo-Charger.		
R.P.M.	8,800	8,200
Charging air temp. °F. ...	93	100
Charging air press. "Hg....	4.4	3.4
Charging air quantity, cu. ft./hr.	112,000	107,000
Ambient air temp. °F. ...	58	70
Barometer "Hg.	29.62	30.3
Exhaust temp. (inlet to charger) °F.	740	650
Exhaust back press. (at charger) "Hg.	3.95 (mean)	2.05 (mean)

The turbine was altered to provide three gas entries, and three manifolds were fitted, as shown in Fig. 6. The data given in Column B of the Table are those obtained in this condition. It will be noted that engine loading is carried to 55 per cent. only in both tests. In the case of the two-manifold arrangement operational conditions were such that it was undesirable to carry loading to a higher figure. Full output has been obtained with the three-manifold arrangement with satisfactory temperature and other conditions and an optimum consumption of 0.355 lb./B.H.P./hr. Performance data over the complete load range are plotted in Figs. 8 and 9.

This example illustrates the importance of the scavenging feature. It is, perhaps, more important than the actual charging of the cylinder under pressure. The proper valve phasing is necessary to allow the air to flow freely through the valves and combustion space in spite of the fact that the peak exhaust pressure is higher than the charging air pressure. The valve timing must be such that the exhaust pressure has dropped sufficiently by the time the air inlet valve opens, to allow the air to flow through with the charging air pressure available. Figs. 3, 4 and 5 show the pressure fluctuations in the cylinders and exhaust manifold of a six-cylinder engine of 6 in. bore, 8 in. stroke, with rotational speed of 1,250 r.p.m. The diagrams were made

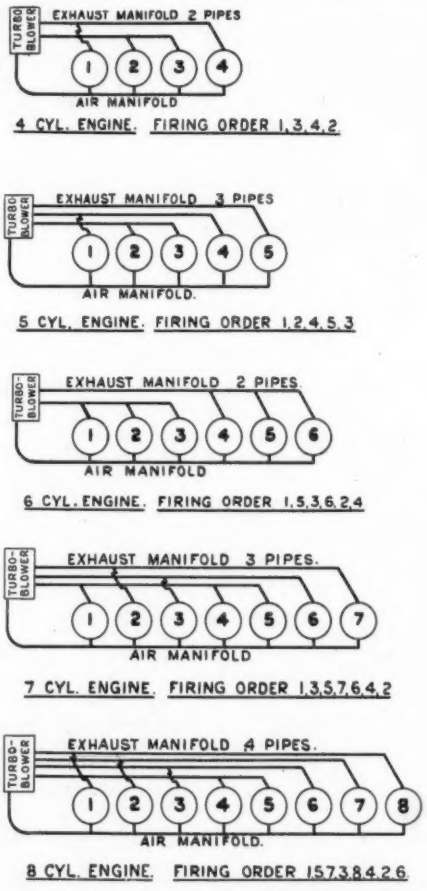


Fig. 6.—Diagrammatic arrangement of manifolds for engines of 4, 5, 6, 7 and 8 cylinders.

with a cathode ray oscillograph. Fig. 5 indicates how the valve phasing promotes the scavenging process. Some 25 per cent. of the air supplied by the blower may be passed through the combustion space into the exhaust system during the scavenge period.

It will be noticed in Fig. 3 that the peak pressure occurs between 10° and 15° after T.D.C., an almost ideal condition giving appreciable

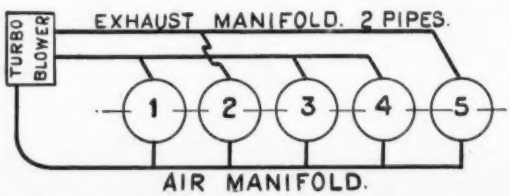


Fig. 7.—Diagrammatic arrangement of manifolds for 5-cylinder engine firing order 1, 2, 4, 5, 3.

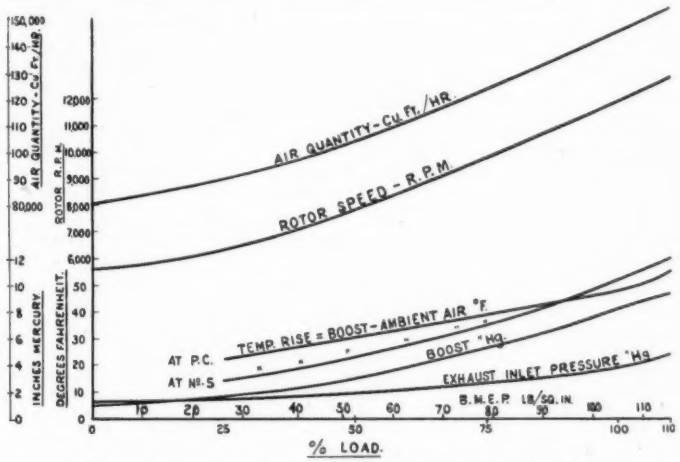


Fig. 8.—Test results for 875 B.H.P. pressure-charged engine.

torque and bearing pressure relief as compared to the conditions involved where virtually constant volume combustion applies. The particular engines of the class giving the diagrams shown in Figs. 3, 4 and 5 are notable for their quietness and smooth running, and it is considered that this characteristic in the cylinder pressures is largely responsible. The introduction, in some degree, of constant pressure combustion of the fuel, means some loss in efficiency, the loss increasing as the quantity of fuel burnt at constant pressure is increased. This condition cannot be avoided, as, in order to ensure good starting, the compression pressure must be maintained at a figure which gives ignition temperatures in cold conditions. With true constant volume combustion and the compression pressures found necessary, the maximum pressure would reach a figure beyond practicable value. The burning of part of the fuel at constant pressure eases the conditions and enables the extra power to be obtained conveniently. In the engines in discussion, the loss in efficiency is not great and low fuel consumptions are recorded regularly, together with terminal temperatures well below what could be accepted. The smoothness of operation more than outweighs any advantages in cycle efficiency gained by constant volume combustion and its associated high maximum pressures.

The slight rise in pressure in the middle of the exhaust stroke (Fig. 3), is due to the pistons building up pressure during the period of maximum velocity. The diagram is taken from No. 3 cylinder, which is coupled to the short exhaust pipe, and the indication is that the gases flow fairly freely under normal expansion before the point of maximum piston speed is reached.

The curious sudden and short period rise in pressure just before T.D.C. is not really a condition existing in the cylinder. The pistons used have a very broad flat land, with small bumping clearance. The inner end of the indicator connection passage is directly over the centre of this land. At dead centre the air in the passage is compressed, so giving an artificial reading over this small period.

The slight rise in pressure during the induction stroke, about 80° after T.D.C., occurs just after the exhaust valves close. This is then a "ramming" effect, indicating a sudden cessation of the flow through the exhaust passages, the velocity energy being immediately transformed to pressure. This is proof that scavenging is occurring right up to the point of closing of the exhaust valves.

Cylinder Low-Pressure Diagrams.

Fig. 4 shows cylinder low-pressure diagrams taken from the same engine. An interesting feature in these diagrams is the effect of exhaust pipe volume. From Fig. 6 it will be noted

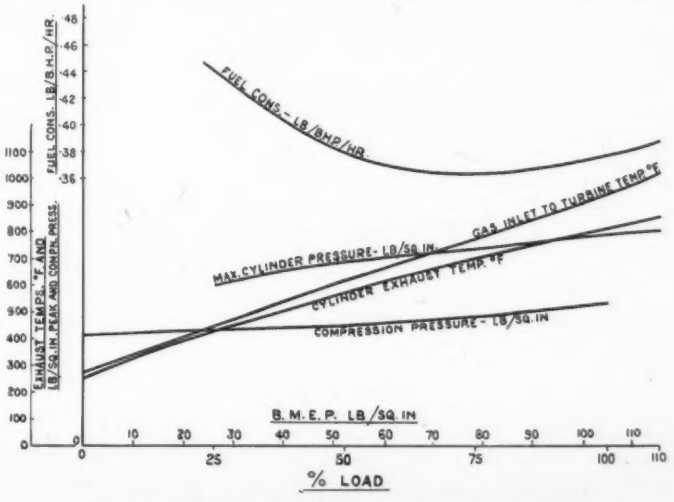

FUEL CONS. - LB/BHP/HR.
GAS INLET TO TURBINE TEMP °F
MAX. CYLINDER PRESSURE - LB/SQ.IN.
CYLINDER EXHAUST TEMP. °F
COMPRESSION PRESSURE - LB/SQ.IN.
FUEL CONS. LB/B.H.P./HR.
EXHAUST TEMPS. °F AND LB/SQ.IN. PEAK AND COMPN. PRESS.
B.M.E.P. LB/SQ.IN.
% LOAD

Fig. 9.—Test results for 875 B.H.P. pressure-charged engine.

that cylinders 1, 2 and 3 are coupled to the short exhaust manifold, and 4, 5 and 6 to the long. The outstanding characteristic in the Fig. 4 diagrams is the noticeable differences in the rates of pressure fall in the cylinders. This reduction is more rapid in cylinders 4, 5 and 6, due to the greater manifold volume between the cylinders and the turbine nozzle ring. As this pressure drop becomes more rapid, the effect of the piston speed becomes more marked, and is indicated as a small hump in the expansion curve. The cathode ray apparatus is sufficiently sensitive to show quite clearly the increase in the local pressure change as the rate of general pressure reduction increases progressively from cylinders 4 to 6. In cylinders 1, 2 and 3, the effect of maximum piston speed is merely a slowing down of the rate of pressure drop.

The effect of the air compression in the indicator passage is seen clearly in all cylinders.

Exhaust Manifold Diagrams.

Fig. 5 shows the exhaust manifold conditions. Here again the differences between the short and long pipes are seen to be marked, and to coincide with the characteristics of the cylinder diagrams. The pressure fluctuations are phased almost perfectly. The low pressure periods occur in exact synchronism with the overlap of exhaust and air valves, the flow of scavenge air taking place when the pressure in the exhaust pipe is lower than the charging air pressure. The effect of the wave set up by the piston motion is more apparent in the longer pipe than in the shorter, indicating the freer expansion of the gases in the larger volume of the longer pipe.

The form of the pressure fluctuations shows clearly how the gas column moves, without reversal, in the direction from cylinder to exhaust pipe and turbine.

All the diagrams taken by the cathode ray apparatus, that is, Figs. 3, 4 and 5, showed waves of small magnitude superimposed on the general line of pressure change. The frequency is fairly high and it is thought that the instrument has registered the effects of sound waves being reflected from the virtually closed ends of the passages concerned. The wave velocity would, in the relatively dense, high temperature medium be appreciably in excess of the normal figure for atmospheric conditions. The diagrams taken by the "Farnboro" indicator showed fairly broad bands of punctures roughly analogous, when joined up, with the characteristics observed on the cathode ray diagrams. In the drawing of Figs. 3, 4 and 5 this waviness has been smoothed out. Clearly the magnitude of the sound waves is so small that no effect on the pressure conditions can be visualised.

Figs. 8 and 9 give a comprehensive picture of the pressures, temperatures, etc., in an engine and pressure-charger at various loads. Figs. 10 and 11 show the heat balance, on a percentage basis, for two different engines; it will be seen that the thermal efficiency is practically constant over a wide range of load. Table II shows the maximum and compression pressures for three types of engine over the whole load range :—

TABLE II.

6SH Engine.						
Load % ...	0	25	50	75	100	110
B.M.E.P. lb/sq. in.	0	25.5	51	76.5	102	112.2
Max. „	830	860	880	890	960	1,010
Compression lb./sq. in.	518	532	555	586	622	638
8SK Engine.						
Load % ...	0	25	50	75	100	110
B.M.E.P. lb./sq. in.	0	29	58	87	116	127.6
Max. „	503	610	672	713	756	772
Compression lb./sq. in.	432	452	490	538	589	608

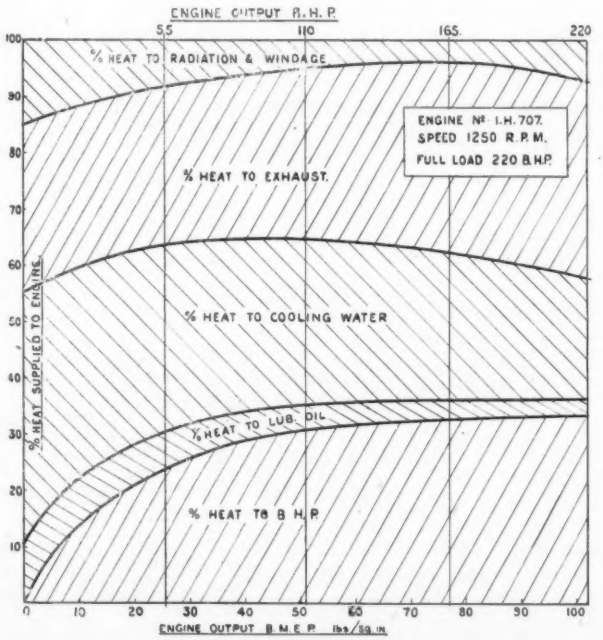


Fig. 10.—Heat Balance—6-cylinder pressure-charged H-type engine.

	5SL Engine.					
Load % ...	0	25	50	75	100	110
B.M.E.P. lb./sq. in.	0	26.25	52.5	78.75	105	115.5
Max. Compression ,, lb./sq. in.	518 415	622 427	688 450	739 492	787 540	807 560

The reaction of engine and blower to load variation has been a matter of some uncertainty, and this aspect of operation has been investigated. The speeds of blower rotors of fairly widely differing sizes were measured electrically to ascertain the speed changes in various conditions. Fig. 12 shows the blower speed variation and governing of an 8-cylinder engine when the load (electrical) was thrown off. The governor, in this case, is a hydraulic servo-piston type, designed and manufactured at the Rugby works of the Company. It will be noted that the total K.E. of engine, flywheel and generator is only 1,040 ft.lb. per B.H.P. This accounts for the somewhat higher than normal momentary variation of engine speed. The flywheel, in this particular instance, is the standard for a naturally aspirated engine of the same dimensions, speed and number of cylinders, and undue momentary speed rise is to be expected in the circumstances. Normally, flywheels of increased K.E. are fitted to pressure-charged engines.

Fig. 13 shows the conditions (same engine) with full load thrown on. It will be noted that the engine speed has settled to a steady value some appreciable time before the blower rotor has attained its normal full-load speed, and it is evident that the engine is capable momentarily of full load when the blower is supplying something less than full load air. The effect of this condition is a short period rise in exhaust gas temperature and some colour in the exhaust. Temperatures and exhaust discharge conditions become normal as soon as the blower speeds up. The momentary rise in exhaust temperature assists in reducing the time taken by the blower rotor to reach normal speed.

Figs. 14 and 15 show similar data obtained from a smaller higher speed engine and D.C. generator. In this case the governor is again of "English Electric" design and manufacture, but not with hydraulic operation of fuel rack. The momentary speed variation is somewhat less in spite of the still lower value of flywheel K.E. per B.H.P. This is to be expected, as some time lag, however small, is inevitable with a servo governor as used on the larger engine.

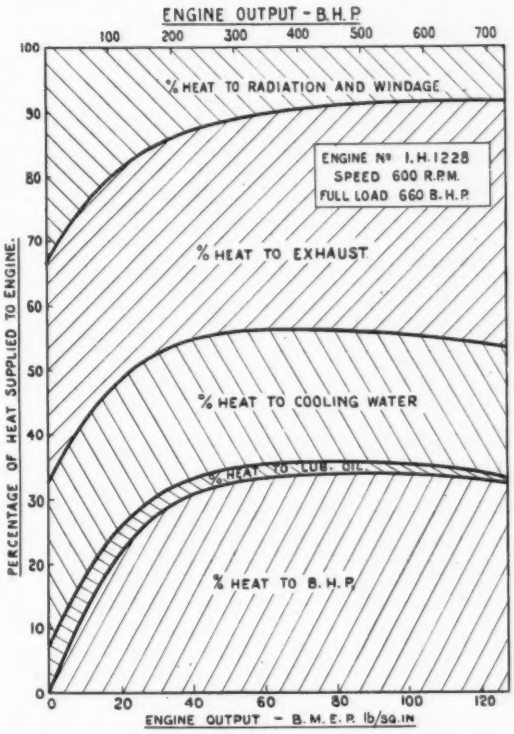


Fig. 11.—Heat Balance—8-cylinder pressure-charged K-type engine.

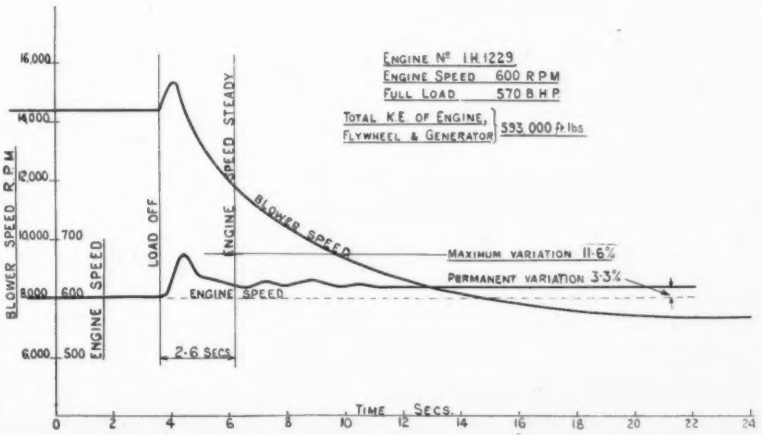


Fig. 12.—Blower speed variation and governing characteristics of an 8-cylinder, 600 R.P.M. engine when full load has been thrown off.

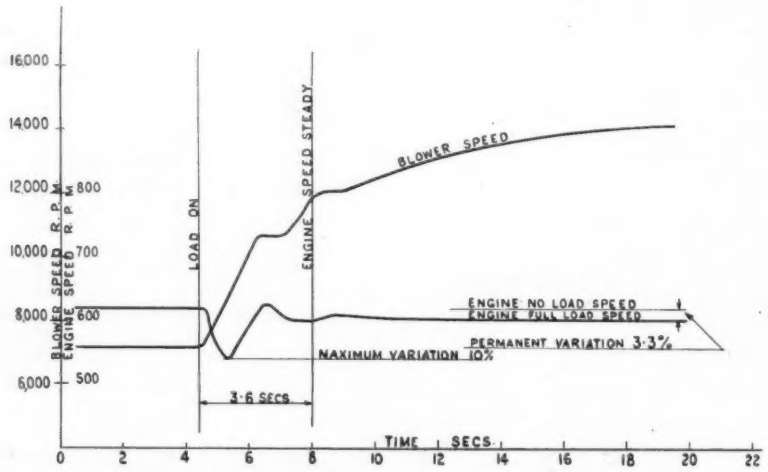


Fig. 13.—Blower speed variation and governing characteristics of an 8-cylinder, 600 R.P.M. engine when full load has been thrown on.

In the case of engines for traction purposes, particularly where shunting duties are involved, the question of low load conditions arises. At no load, with a constant speed engine, the blower speed is about 50 per cent. of its speed at full load—see Figs. 12 and 14. Even at this low speed, there is more air delivered than would be inspired by an uncharged engine. In the case of shunting locomotives where considerable periods of no load at idling speed have to be considered, non-return valves in the air manifolds have been used by certain manufacturers to allow natural aspiration to take place if the air supplied by the blower falls to too low a value. Extensive experimental running at low speeds (down to as low as .4 of the normal speed) with no load, carried out at the company's works, has not indicated that such valves are necessary.

An interesting and valuable characteristic of turbo-charged engines is their ability to develop considerable outputs with the blower rotor out of action. Experiments have been carried out on a 10 in. × 12 in. four-cylinder engine, the blower rotor of which was clamped stationary. It was found that, without undue temperatures in cylinders and exhaust system, full naturally aspirated load was carried and held without any signs of distress or deterioration. The specification issued by a Service Department in connection with the construction of a number of higher speed six-cylinder engines required the first engine of a batch to be tested with the blower rotor locked. In this condition, and without any preparation or special adjustment, 90 per cent. of the naturally aspirated full load of the engine was held comfortably with constant temperature conditions. There is no doubt that with the rotor and nozzle ring removed, the performance would have improved, since the nozzle ring discharge area is considerably smaller than the area of the exhaust pipes and passages. The absence of the blower element would, in addition, give freer flow for the inspired air and increase the volumetric efficiency of the engine. These tests were very important in that they established, on two engines of fairly widely differing characteristics, that, under emergency conditions, approximately the uncharged rating can be carried if the turbo-charger becomes inoperative.

There are few data available yet in regard to the maintenance costs on turbo-charged engines as compared to naturally aspirated engines. The experience of The English Electric Company is that no additional costs are apparent. Careful observation of one fairly large engine which has been in operation for a number of years indicates that the general condition is better than when this same unit operated in the naturally aspirated

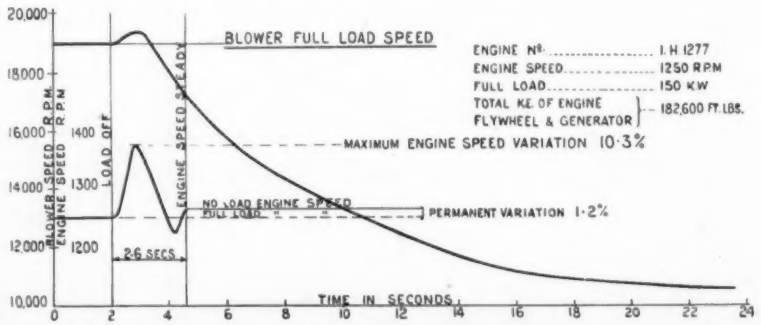


Fig. 14.—Blower speed variation and governing characteristics of a 6-cylinder, 1250 R.P.M. engine when full load has been thrown off.

condition. The turbo-blower has been completely trouble free. Internal examination after several thousand hours operation showed all parts to be in excellent condition. A second and smaller engine has borne out the experience with the larger unit. In this smaller installation trouble was experienced in the early running with fibrous dust from process work. The engine valves and blower quickly became affected. The fitting of an air filter on the blower inlet removed very effectively all difficulties. A third and still smaller higher speed engine has likewise shown no increase in necessary maintenance. In all cases the general operation has been quieter and smoother than is the case with non-charged engines of the same type.

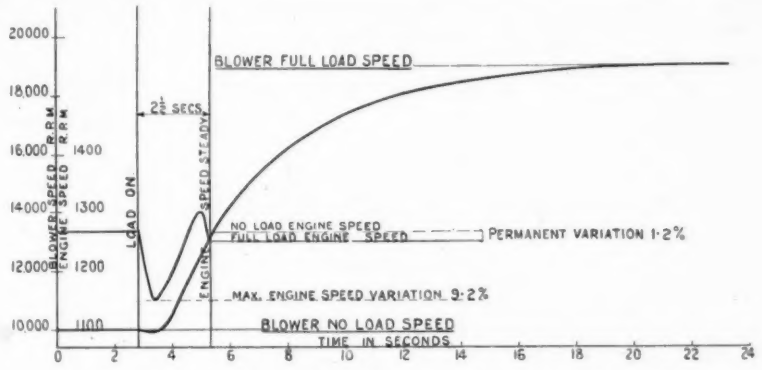


Fig. 15.—Blower speed variation and governing characteristics of a 6-cylinder, 1250 R.P.M. engine when full load has been thrown on.

The American Locomotive Company has compiled details of the cost of operating its Diesel-electric locomotives. Two classes of shunting units are concerned, one with 660 H.P. six-cylinder naturally aspirated engines and the other with 1,000 H.P. turbo-charged engines. The latter engines are exactly the same as the former except that they are turbo-charged, the boost being approximately 50 per cent. Both types of locomotive are one to four years old. Recent figures indicate that the maintenance costs for the smaller locomotives are 28 cents per hour, whilst the figures for the locomotives with the 50 per cent. more powerful pressure charged engines come to 29 cents per hour.

It has been observed, however, that with the materials at present available and with blower design in its present state of development, the continuous operation temperature of gas entry to turbine should not exceed about 950 °F. The experience of one insurance authority has been that in all cases where this figure has been habitually exceeded, rotor trouble has occurred.

Difficulties with resonant vibration of the blades are not unknown and this aspect requires the special consideration of the turbo-blower designer. The problem here it seems is involved with the frequency of the gas impulses from the engine cylinders. Cases have arisen where a rotor which operated quite satisfactorily with one number of cylinders, has failed in a matter of an hour or so of running associated with a different number of cylinders. In this instance a resonant condition with full build up of blade vibration amplitude would appear to be indicated.

The short length of the rotor shaft makes it possible to design for the location of the first critical (whirling) speed to be well above the maximum running speed of the rotor. This is an important point as the operating conditions involve variable speeds over a wide range.

The turbo-charger is a relatively simple machine, self-regulating in operation. There are no controls or adjustments. The rotor speed, and hence blower output, adjust themselves automatically to load conditions. The speed and air output depend upon the quantity of exhaust gas flowing through the engine and this, in turn, is a function of engine load and speed. A large percentage of the power for driving the blower is obtained without any debit against the engine and, in consequence, fuel economy is good with a flat curve over a wide range of load.

These characteristics make the system particularly suitable for rail traction or marine duties. In both classes of work the engine speed and the power demand are essentially variable. In these conditions the turbo-blower adjusts itself rapidly and automatically to the changing power requirements.

The ultimate potentialities of pressure-charging are as yet largely unexplored. High mean cylinder pressures have been achieved on experimental test beds, with single-stage turbo-chargers and without cooling of the charging air. Multi-stage blowers and after-cooling should permit additional increases in the power boosts. It seems evident, however, that further progress is likely to be largely a question of advances in metallurgy in order to permit of commercial use of higher temperatures. Notwithstanding the appreciably higher B.M.E.P.'s achieved in experimental work, it seems evident that in day-to-day operation, about 125 lb./sq. in. is the maximum figure which can be associated with reliability. A value below 1,100 °F. is considered at present to be the limit for gas temperatures at entry to turbine. There is little doubt, however, that increasing knowledge of combustion and associated problems, together with accumulating operational experience, will clear the way to further achievement, and that the four-cycle pressure-charged Diesel engine is likely to show rapid development in the direction of higher boosts and consequent reduction of specific weights and dimensions.

D. Napier & Son Limited.

Foreword by the Chairman, Sir George H. Nelson.

The English Electric Company, in furtherance of its war effort, acquired the whole of the ordinary shares of the Napier Company and as that organisation is now part of the "English Electric" team, both in its war effort and peacetime activities, this section of the "Journal" will henceforth be devoted to matters associated with Napier activities and products.

In this, the first issue, a precis of the history of this old established company is given so that readers may know something of its long and successful record. Future issues will contain technical articles by members of the Napier organisation, items of news, and matters of special interest.

I am confident that readers will welcome the introduction of this Napier section as a feature of the "Journal" in the belief that it will prove to be of added interest.

George H Nelson

The company was founded in 1808 by Mr. David Napier, who was connected with an engineering business in Inverness. He sailed to London and commenced business on his own account in Soho, at No. 1, Lloyds Court, St. Giles.

An early patent taken out in his name covered improvements in printing machinery. Later plans for an improved steam carriage were patented but the difficulty of constructing a light and satisfactory boiler was not overcome and the carriage was not a success.

Apparently David Napier's object in founding his business at Lloyds Court, St. Giles, was primarily to make printing machines. Previous to 1798, printing presses were constructed of wood, and being a mechanic of inventive ability he foresaw that he might profitably apply his skill and ingenuity to devising and making printing machines, and that London, as the news centre of the country, would offer the best prospects in which to set up his business.

In 1824 David Napier constructed a printing press for Hansard, who, in his "Typographia," published in 1825, gives an historical sketch of the origin and progress of the art of printing, and mentions David Napier as the inventor of a new type of press which effected a considerable saving in labour. This machine could ordinarily operate at a speed of 2,000 impressions per hour, and occupied a space about 5 ft. by 10 ft.

The earliest available record of transactions of the firm is dated 1832, when a printing machine was supplied to the "Morning Post" at a cost of £440. Hansard also, in this same period, acquired a printing machine "worked by steam." The Trade Name for this machine was styled Nay-Peer. If not the first, this was one of the earliest recorded attempts to introduce power-driven printing machinery.

About this time the factory was removed from Lloyds Court and established at Vine Street, York Road, Lambeth. This new works was equipped with a smith's forge, a pattern-maker's shop, a planing machine, a screw-cutting lathe, some treadle lathes, and "... a wheel-cutting machine." The treadle lathes were operated by apprentices.

In 1833 a special machine was constructed for making compressed musket and rifle balls and in 1842 a number of these machines were supplied to the Royal Arsenal, Woolwich. Before this machine was introduced the common cast bullet contained a small air-bubble, which apparently, had its effect upon the accuracy of the shooting.

In 1840 the name of the Great Western Railway Company is recorded as a customer. Hydraulic machines were supplied to the goods dept., "... at the Bristol terminus." Later, overhead travelling cranes were also supplied.

In 1843 the Bank of England purchased "... three 'Patent' coin weighing machines, complete with all improvements, a small vacuum engine, the necessary shafting, pulleys, etc., a gunmetal air-pump with parallel eccentric motion, etc." The value of this order was £1,000. Also, during this same year the Board of Ordnance was supplied with a complete gun-boring and turning-lathe, a planing machine and other equipment to a total value of £2,850.

Napier's work on his "Automaton" coin-weighing machine commenced in 1842 when an experimental model was supplied to the Bank of England. It was claimed that this machine could weigh 10,000 sovereigns in six hours and could divide coin varying by only 1/50th of a grain. Before the introduction of this machine coin was "hand weighed" at a rate of three-thousand sovereigns in six hours, on scales which were unable to record closer than 1/25th of a grain.

In 1847, Napier took his son James Murdoch into partnership and the business assumed the title of D. Napier & Son. The books record the value at that time, of "... premises, plant,

etc," at the sum of £11,664 2s. 5d. During the period 1847-1866 a quantity of gun-finishing machines was supplied to the Spanish Government and also to the Imperial Arsenal, St. Petersburg. Work continued for the Board of Ordnance, and other items manufactured and sold were a tide-gauge for the Admiralty, coin machines for the Mint, a hydraulic press for hot-pressing, an envelope printing machine, an astronomical telescope, stamp-perforating machines for Somerset House, and a sugar mill. In 1854 the Crimean war brought considerable orders for reversing gear-quadrants, bilge-pumps, rifle-rods, etc., and for " . . . boring out cannon thirty-three feet long and rifling same with three grooves 5 ft. 5½ in. pitch."

The supply of printing machines to many customers in the United Kingdom and abroad, appears to have been the mainstay of the business but from 1866 the volume of business receded so seriously that in 1895 seven men only were employed on the few orders obtained for coin-weighing machines. In that year Montague Stanley Napier, grandson of the founder David Napier purchased the goodwill, plant, patents and leasehold premises at York Road, and from this period the business began to revive. The development of small machine tools was undertaken and for a few years much attention was paid to this branch of the business. Older readers will remember that during the " nineties " there was a temporary wave of enthusiasm for road roller skating. Napier produced a " novel " design of skate which appeared to have enjoyed a measure of success.

It was in 1898 that the real turning point in the business came when the first Napier engine (Fig. 1) for a motor car was produced. This engine represented the first step towards the attainment of the high reputation which the Napier motor-car ultimately reached in later years. It was of two-cylinder construction, developed 9 H.P., and weighed over 300 lbs. ; it was fitted to the first Napier car, which, in 1900 took part in the Automobile Club's 1,000 mile trial, starting at Hyde Park Corner. Newspapers of the day described the Napier car as accomplishing " . . . the most meritorious performance of the trial." The result of this trial clearly established a reputation for Napier cars, and later in the same year a four-cylinder 16 H.P. model made its appearance. This new model included striking improvements, the most noteworthy being the introduction of " a single aluminium block incorporating the water jacket in which cast-iron cylinder liners were inserted under a press." The head containing the inlet and exhaust valves was detachable. In 1904 Napier produced the first six-cylinder motor-car, and it was shown to the public for the first time at the Crystal Palace Motor Exhibition held in that year.

Napier cars had by this time established a good name for reliability but in 1907 this reputation was greatly enhanced by the magnificent performance set up by three six-cylinder cars which ran on Brooklands Track for 24 hours, without a stop, except for re-fuelling and change of drivers. The distance covered by the leading car was 1,581 miles, an average of 65.8 miles per hour. It was recognised to be an ambitious test in those days but the result proved that the confidence held in the outstanding quality of the Napier car was amply justified. We are pleased to record that one of the drivers in that memorable trial, Mr. H. C. Tryon, is still with the Company as a member of our Research Staff.

In 1903 the business was removed to its present address at Acton, and in 1906 was incorporated as a limited company.

Concurrently with the rapid progress made in the motor-car industry, development work on petrol engines for marine purposes was carried on and many cruising launches and high-speed motor boats were designed and produced.

For the earlier period of the war years of 1914-1918 the company was busily engaged on Government contracts for staff cars, lorries, ambulances, etc., but during this period attention was first given to the manufacture of aircraft and aero engines, by the acceptance of Government Contracts for the production of both airframes and engines of official designs. In 1917 the design

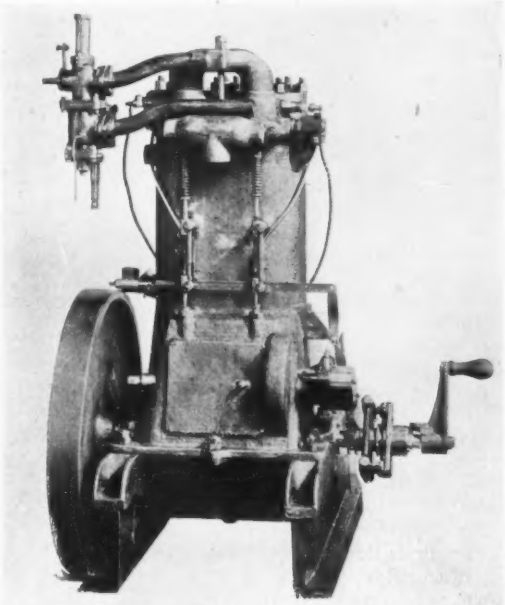


Fig. 1.—9 H.P. Napier car engine built in 1898, it has a weight/power ratio of 37.3 to 1.

and development of the Napier "Lion" aero engine was commenced. The engine was not completed in time to participate in the war, but for a period of ten years from 1919 the "Lion" engine achieved an enviable record of success throughout the whole world. It was used in quantity in all types of R.A.F. and civil aircraft and by many of the countries of the world. On two occasions the Schneider Trophy was brought back to Britain by a Napier engine. The victories gained and records set up in other air races and trials are too numerous to relate in a short article.

The world's land speed record has been held by Napier engined cars on numerous occasions and at the present time is held by John Cobb and his Napier-Railton car at a speed of 369.74 M.P.H., set up in August, 1939. The Napier-Railton car is fitted with two special Napier racing engines built in 1930.

To meet the demand for air-cooled aero engines, Napier's introduced the "Rapier" in 1932. This can be claimed as the first successful twin-crank multi-cylinder aero engine and formed the basis of Napier development of this arrangement, known as the "H" type.

The "Rapier" was fitted in the Fairey "Sea-Fox," a fleet-spotter aircraft, which was carried as part of the equipment of certain cruisers of the Royal Navy. Throughout the Battle of the Plate, the crew of the "Sea-Fox," catapulted from H.M.S. "Ajax" directed the fire of the cruisers "Exeter" and "Ajax" with such accuracy that the enemy battleship "Graf-Spee" was crippled and took refuge in the neutral waters of the River Plate. The successful conclusion of the battle will be well remembered as one of the great naval victories of the war.

The "Rapier" was also fitted in the four-engined seaplane "Mercury," the upper component of the "Mayo" composite aircraft, and held the long distance record for seaplanes, of 6,045 miles, set up during the flight to Walvis Bay, South Africa, in 1938.

In 1936 development of an engine for high-speed motor boats for the Royal Navy and the Royal Air Force was commenced. The worthy old "Lion" was taken as a basis and after a short period of development the engine now known as the "Sea Lion" emerged. Many hundreds of these engines are giving excellent service in the Royal Navy, and the Royal Air Force Air-Sea Rescue Service. The first flotilla of these "little ships" proceeded to their station at Malta under their own power and negotiated the rough waters of the Bay of Biscay without incident.

Also in 1936 the decision was made to design and manufacture an aero engine of the 2,000 H.P. class. This engine, now known as the "Sabre" (Fig. 2), successfully passed the Air Ministry 100 Hours Standard Type Test in June, 1940, and was immediately put into quantity production, with a rating of 2,060 H.P. for a weight of 2,250 lbs. Since that date development has continued and the "Sabre" 11A, fitted as standard equipment of the Hawker-Typhoon Fighter Bomber and Rocket firing aircraft has a power output of over 2,200 H.P.

The "Typhoon" first went into combat with the Luftwaffe on the occasion of the Dieppe raid in 1942, and very soon established its position as Britain's most formidable fighter. Typhoon squadrons provided the low altitude air cover over the beaches on "D" Day, with results well-known, and as fighters, fighter bombers, or rocket-firing aircraft have been the subject of almost daily reports and news items. Readers will recall that on a particular day in August, 1944, Rocket-Firing Typhoons attacked and broke up a powerful enemy attempt to break through the Allied line at Argentan. On that day 139 enemy tanks were destroyed or disabled and the action formed the turning point of the Battle of Normandy.

The "Tempest," Britain's latest fighter, fitted with a "Sabre" engine of still higher power, came into prominence as the only aircraft possessing the speed and fire-power to catch and destroy the flying-bomb during the recent attack on London and Southern England. An official statement records that a wing of "Tempests" shot down well over 600 of these missiles in a short period.

The "Tempest" has now joined in active operation in the maintenance of the Allied mastery of the air over the battlefields and continues to perform its duty with distinction. But here we must draw the veil of "security," and leave for a future issue further details of the performance of this latest and finest example of Britain's fighter aircraft.

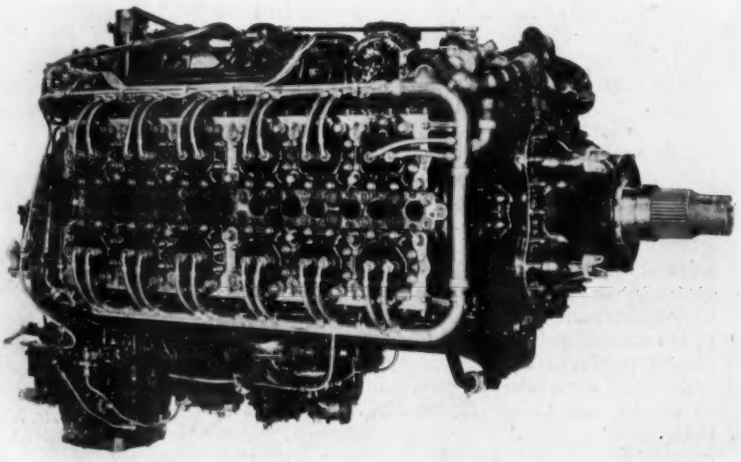


Fig. 2.—The 2,200 H.P. Napier "Sabre" aero engine, it has a weight/power ratio of 1.07 to 1.